Relationship between ERS Scatterometer Measurement and Integrated Wind and Wave Parameters

Y. QUILFEN AND B. CHAPRON

Département d'Océanographie Spatiale, Centre de Brest, IFREMER, Plouzané, France

F. COLLARD

BOOST-Technologies, Plouzané, France

D. VANDEMARK

NASA Goddard Space Flight Center, Wallops Flight Facility, Laboratory for Hydrospheric Processes, Wallops Island, Virginia

18 April 2003 and 30 August 2003

ABSTRACT

Potential effects of environmental parameters such as sea state or atmospheric boundary layer stability on the normalized radar cross section (NRCS) measured by spaceborne sensors have been investigated for a long time. Using neural networks and large high quality collocated datasets, the relation between the European Remote Sensing Satellite (ERS) C-band scatterometer NRCS measurement and integrated sea state parameters (i.e., the mean wave period and significant wave height) measured by buoys is studied. As anticipated, NRCS measurements correlate well with an empirically derived parameter H^{α}/T^{β}, revealing the mean bulk relationship between a mean 10-m wind speed and the corresponding sea state development. The correlation and exponents exhibit dependency on the scatterometer incidence angles. A neural model that relates the scatterometer NRCS measurements to these wave spectral integrated parameters and wind speed is also developed. As obtained, the retrieval skill is significantly improved, by comparison with operational empirical models such as CMOD-IFR2 or CMOD4, when including wave effects. As illustrated, systematic biases occur under particular environmental conditions when using the operational scatterometer backscatter model functions.

1. Introduction

Model functions relating measured altimeter and scatterometer normalized radar cross sections (NRCSs) to near-surface wind have been thoroughly tested over the past years. Requirements are met, but studies based on collocated satellite, model, and/or in situ estimates still reveal relatively large scatter (Graber et al. 1996). Measurements and numerical predictions, as well as the empirical model functions, do contain errors. For altimeter and scatterometer instruments, cases of erroneous wind inversions have been documented and shown to be related to the presence of surface currents, surfactant, temperature fronts, atmospheric stratification, and precipitation (e.g., Keller et al. 1989; Vandemark et al. 1997; Weissman and Graber 1999). There is also evidence that the sea state maturity can affect the radar measurements. Indeed, experimental results show that the ocean's drag coefficient depends on sea state (e.g., Donelan et al. 1993) to influence the wind stress and to impact small-scale roughness development, and thus the measured backscatter intensity. An increasing influence of the surface drift on short-wave dissipation (e.g., Banner and Phillips 1974; Quilfen et al. 1999) can also be invoked to suggest that local sea state conditions (current, sea state maturity, wind/swell direction alignment) will impact radar wind inversion. This sea state influence on altimeter measurements is already well documented (Chen et al. 2000; Queffeulou et al. 1999; Gourrion et al. 2002a,b). Theoretical backscattering models accounting for sea state effects, crucial to physical understanding, have also been developed but show limited skills for operational purposes. To our knowledge, an empirical development taking into account a sea state parameter has only been successfully derived for Ku-band altimeters and is currently operational for the altimeter wind inversion (Gourrion et al. 2002a,b).

In this note, we focus on C-band scatterometer data. A neural model is developed to relate the radar cross section to both surface wind and sea state information. As tested, this provides significant improvement on scatterometer-retrieved wind estimates. In section 2, the datasets and methods used in the study are presented. In section 3, an analysis of the relationship between European Remote Sensing Satellite (ERS) C-band measurements and the integrated wind and sea state parameters is given. In section 4, illustrations are shown to reveal strong local effects and obtained improvements. Discussion follows in section 5.

2. Data and methods

The analyses are based upon sets of *ERS-1* and *-2* scatterometer measurements collocated with the National Data Buoy Center (NDBC) buoys. Scatterometer data are processed offline at the French Research Institute for Exploitation of the Sea (IFREMER) using the

Corresponding author address: Dr. Yves Quilfen, Département d'Océanographic Spatiale, Centre de Brest, IFREMER, Technopole de Brest-Iroise, B. P. 70, 29280 Plouzané, France.
E-mail: yves.quilfen@ifremer.fr

CMOD-IFR2 backscattering model to compute the 10-m neutral wind (Quilfen et al. 1998). The NDBC data have been collected over the period September 1992–January 2001 by 48 buoys. These buoy measurements are converted to 10-m neutral winds using a log-profile relation accounting for the atmospheric stability. In this study, the closest buoy 1-h average estimates to the time of *ERS-1* or *-2* overpass is collocated with scatterometer data. The separation distance between measurements is less than 25 km. As found, 36 218 collocated data pairs have been compiled. We take the convention that ''wind speed'' stands for the neutral stability wind measured at 10-m height.

Taking advantage of buoy wave measurements, we use a methodology based upon neural networks to define the geophysical model function (GMF) relating the scatterometer NRCSs to the buoy wind and wave parameters. The procedures used are those of the MATLAB neural toolbox (The MathWorks, Inc.).

3. Relation of NRCS with the integrated wind and wave parameters

We first establish the link between the NRCSs and the sea state parameters. This helps to derive a neural model and interpret the relationship between the NRCSs and both the wind and wave parameters.

a. The NRCS to integrated wave parameters relation

We develop and train the following neural model:

$$\sigma_1 + \sigma_3 = a\left(\frac{H^\alpha}{T^\beta}\right) + b, \tag{1}$$

where H and T are the buoy-integrated significant wave height and mean wave period, respectively; α and β are constant exponents; σ_1 and σ_3 stand for the aft and fore beam NRCSs, respectively; and a and b are incidence angle dependent coefficients. The sum of the aft and fore beam NRCSs filters out most of the wind direction effects.

As understood, a wind blowing over the ocean surface will rapidly roughen the surface. With time or fetch, the sea develops and similarity laws apply (e.g., Kitaigorodskii 1973). Thus, on average, backscatter measurements are expected to correlate with integrated sea state parameters. The choice of the parameter H^α/T^β also comes from previous results, showing that C-band model residuals (observed minus predicted NRCS) are correlated with such a parameter (Quilfen et al. 2001).

The neural model outputs are the two exponents α and β, and the simulated NRCS. Evaluations are performed from data subsets at the different incidence angles corresponding to the 19 scatterometer nodes covering the swath across the satellite track. In Fig. 1a, we observe nearly constant values for the exponents, except at the lowest incidence angles, where values are slightly lower. Mean values are close to 1.5 and 2.5 for α and β, respectively. As obtained, the NRCS dependency is not strictly related to a significant slope parameter ($\sim H/T^2$). According to the exponent values, it is rather a combination (product) of the significant slope and the square root of the significant velocity ($\sim H/T$) parameter. Finally, since the CMOD-IFR2 model roughly predicts the NRCS to depend on the square root of the wind speed, these exponent values are very consistent with the known high correlation of nondimensional wind sea energy to inverse wave age (Hanson and Phillips 1999; Donelan et al. 1992). Specifically, these studies have led to the relationship

$$\frac{H^2}{T^\gamma} \sim U^{4-\gamma}, \tag{2}$$

where γ is a constant. With $(\sigma_1 + \sigma_3) \sim U^{0.5}$ and the two exponents values found in this study, we find $\gamma \sim 3.3$. This γ value matches exactly the Lake St. Clair (Michigan/Ontario, Canada) observations of Donelan et al. (1992). It also confirms the approximate NRCS square root wind dependency. Recovering such a relationship using scatterometer data thus confirms the relatively marginal impact of swell-dominated open ocean conditions on scatterometer measurements for moderate to high wind conditions. These results imply that, statistically, sea state contributions not directly associated with the local forcing are certainly of second order. However, it must be noticed that at the lowest incidence angles, the α and β exponent values are different and tend to $\beta \approx 2\alpha$. As mentioned above, this corresponds to proportionality with an integrated significant slope parameter. Accordingly, for these incidences, deviations from mean swell steepness conditions shall certainly more significantly impact C-band scatterometer signals.

5. Summary

Sea state conditions certainly affect measurements made by scatterometers. The importance of including sea state parameters in model inversion is still open for debate, but increased correlations have been obtained when considering large-scale integrated wave parameters. Compared to previous attempts, this study certainly benefits from the large number of high quality collocated datasets. While the impact of various sea state parameters (wave age, wave height, etc.) has been thoroughly studied from field experiments, such a unique dataset enables us to derive practical empirical models to be tested further. These first results are encouraging and of interest both in the pursuit of a better understanding of how short and long waves interact and for the practical purpose of developing algorithms to infer wind and wind stress from scatterometer measurements and also from synthetic aperture radar data. In particular, for the lowest incidence angles, the sea state steepness shall be accounted for. As foreseen, information provided by a wave forecast and/or altimeter measurements may be included in such empirical wind retrieval algorithms. As suggested, a simple extension shall be to include information on one or possibly two integrated parameters. Following this development, small but systematic well-defined seasonal and regional biases should be better detected to assess accuracy of ocean surface wind and wind stress forcing fields.